THE IMPACT OF REPRESENTATION FORMAT AND TASK INSTRUCTION ON STUDENT UNDERSTANDING IN SCIENCE

by

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ABSTRACT

The purpose of this study is to examine how representation format and task instructions impact student learning in a science domain. Learning outcomes were assessed via measures of mental model, declarative knowledge, and knowledge inference. Students were asked to use one of two forms of representation, either drawing or writing, during study of a science text. Further, instructions (summarize vs. explain) were varied to determine if students' intended use of the presentation influenced learning. Thus, this study used a 2 (drawing vs. writing) X 2 (summarize vs. explain) between-subjects design.

Drawing was hypothesized to require integration across learning materials regardless of task instructions, because drawings (by definition) require learners to integrate new information into a visual representation. Learning outcomes associated with writing were hypothesized to depend upon task instructions: when asked to summarize, writing should result in reproduction of text; when asked to explain, writing should emphasize integration processes.

Because integration processes require connecting and analyzing new and prior information, it also was predicted that drawing (across both conditions of task instructions) and writing (when combined the explain task instructions only) would result in increased metacognitive monitoring. Metacognitive monitoring was assessed indirectly via responses to metacognitive prompts interspersed throughout the study.

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CHAPTER 1

INTRODUCTION

Learning through art and drawing has a long history stretching back to the late 1400s when Michelangelo and Da Vinci created anatomic representations while participating in public dissections (Eknoyan, 2000), expressing their new knowledge through the creation of sculpture, painting, and frescoes. In more modern times, Netter, a physician by trade and an artist by calling, created a new standard of medical illustration by creating highly detailed and realistic anatomic renderings (Washko, 2006). In each of these cases, the generation of visual representations -- whether in the form of anatomic rendering, sculpture, or frescos -- has been thought to foster learning and understanding. Anecdotally, it would seem that creating an external visual representation in the form of drawing aids in understanding anatomy. Learning science research has identified a number of conditions under which drawing or visual generation supports deeper understanding. However, a remaining question is how drawing may compare to other generative representations to promote deeper understanding of learning materials.

1.1 Generative Learning Strategies

1.1.1 Diagrams Promote Deeper Learning

Butcher (2006) studied the effect of multimedia materials that included complex or simplified science diagrams on students' learning outcomes and mental model development. In order to assess mental models of the to-be-learned topic, learners were asked to generate a diagram of the structure and function of the heart and circulatory system. After viewing a tutorial containing text with accompanying diagrams, the accuracy of students' mental models increased (Experiment 1) but increased the most if the diagrams were simple (Experiment 2). In Experiment 2, the participants performed the same tasks with the addition of self-explanations. The self-explanations began as an unprompted activity; however, the experimenter probed for complete and clear responses. Feedback on the self-explanations was also provided. Self-explanation protocols made it possible to examine students' cognitive processing during multimedia learning. This study demonstrated that the participants who were provided with simplified diagrams made more inferences and integrated material more frequently. Thus, a potential explanation of the benefits multimedia materials on student learning is inherent support for integrative processing during study.

Although Butcher's (2006) study provided students with an effective visual representation, it may be important to consider the potential benefits of student-generated visual representations (rather than representations that are provided to them). Van Meter (2001) asked students to draw diagrams after reading with and without experimenter prompting. Van Meter (2001) found that participants who read the material and drew a diagram demonstrated higher scores on posttest measures. Prompting students to compare their diagrams with a provided illustration further increased learning gains; in this research, the strongest learning gains occurred when questions were provided to guide comparison of their self-generated diagram with a (correct) provided diagram. Although this experiment shows the potential usefulness of student-generated visual representations, the provided illustration was a form of feedback for the student about the quality and accuracy of their diagram. Further, students were able to revise their drawings following comparison to the model diagram. Thus, it is not clear if diagram generation or revision without provided feedback would result in similar learning outcomes.

One might assume that the act of generating a visual representation may spur integration processes to an even greater extent than simply processing provided diagrams. The process by which students create a visual representation from text materials has been proposed as the Generative Theory of Drawing Construction (Van Meter, 2001; Van Meter & Garner, 2005). This theory builds upon multimedia learning theory (Mayer, 2002) and describes how learners select, organize, and integrate information as they draw to learn. The learner must select relevant text elements and activate a mental image from those elements, thus creating a connection between text and drawing. As additional information is encountered, students must reorganize both their internal and any external representations to exclude irrelevant or incorrect elements and integrate new, relevant components (Van Meter, Aleksic, Schwartz, & Garner, 2006). Van Meter and Garner's (2005) meta-analysis led them to conclude that observed learning benefits of student-generated drawings are due to the integrative and generative processing required to create the external visual representation with the highest gains seen in students that had some type of external support.

It is important to note that there may be other factors that influence learning outcomes when creating a diagram. Schwamborn, Mayer, Thillmann, Leopold, and Leutner (2010) and Van Meter's (2001) findings demonstrated learning benefits when students generated visual representations; however, the generative process resulted in students spending more time with study materials during learning. The additional time spent with the drawing tasks may be responsible for the increase in learning seen in these conditions. Indeed, Alesandrini (1981) found that benefits of creating external representations decrease when time on task is controlled and with removal of learner support.

1.1.2 Limitations of Drawing as a Learning Strategy

Simply generating a diagram may not be sufficient for meaningful learning. Butcher and Chi (2006) studied the self-generated diagrams of students who learned about the heart and circulatory system from a written text. These researchers found that early flaws in students' diagrams tended to persist throughout learning, despite multiple opportunities for revision and updating. Moreover, these early flaws tended to impact the depth of students' learning. The flawed mental model did not impact factual knowledge development when acquired early in the learning process; however, performance on items designed to assess inferences and integration suffered. In this research, participants drew a new representation (i.e., were provided with a blank sheet of paper at every update interval); thus, it may be important for participants to be able to view, compare, and monitor their thinking, via a visual representation, over time. This possibility has been supported by recent research showing that learners who compared diagrams demonstrated higher gains than learners who simply self-explained an expert diagram (Gadgil, Nokes-Malach, & Chi, 2012). However, it is unclear whether learners will be able to effectively evaluate and detect errors when asked to revise their representations without external support.

1.1.3 A Nonvisual Generative Strategy: Writing

Writing is considered an explicit method of reasoning and understanding, which results in higher learning gains and increased retention when compared to note taking (Davis & Hult, 1997) or verbal explanations (Linden & Wittrock, 1981) (for reviews, see Applebee, 1984; Emig, 1977). Emig (1977) argued that generating written content provides a method to revisit domain information, evaluate, and organize our thoughts. To study the effect of writing, Davis and Hult (1997) had participants complete one of three conditions: 1) participants wrote essays during and immediately after a lecture; 2) participants took notes and reviewed the notes during lecture breaks; 3) participants took notes during a continuous lecture. An immediate free-recall task showed that students who wrote essays remembered more information than students who took notes during a lecture. However, no condition differences were seen in immediate and delayed posttest assessment of knowledge. Thus, essay writing without additional prompting may facilitate memory for content. Applebee (1984) argued that writing does not always increase learning or inference generation due to factors such as task characteristics. Applebee pointed out that assignments such as note taking or answering study questions require little reasoning, resulting in superficial learning of the topic area. Deeper learning of materials is fostered when the student creates inferences. Applebee suggested paring a writing assignment with an analytical essay, which requires reasoning and a defense of a particular stance. In an effort to determine if one writing task resulted in better learning than another, Newell (1984) looked at the impact of note taking, short answer worksheet completion, or analytical essay writing after reading. Note taking and short answer worksheets are activities often used in the classroom; however, analytical essays that require comparisons are used less often. Though all students increased scores from pre- to posttest, there were significantly higher gains by students who were asked to write the analytic essay. Newell postulated that when students were asked to take notes or complete the short answer worksheet they created ‘isolated bits’ of knowledge while the essay required integration of the ‘bits’, resulting in the higher learning gains.

1.1.4 Limitations of Writing as a Learning Strategy

Bangert-Drowns, Hurley, and Wilkinson (2004) performed a meta-analysis of 48 studies and concluded that it was hard to find a relationship between writing and learning. Bangert-Drowns et al. (2004) found that multiple moderators influenced learning outcomes more than the actual writing task. When factoring in grade-level, the length of the assignments (longer assignments showed less gain), reflective prompting, and scaffolding, effects of writing dramatically decreased. Thus, the impact of writing essays on learning outcomes may depend more on how students are prompted to write than on the simple fact that they are developing a written representation.

1.1.5 Direct Comparisons of Drawing versus Writing

Studies contrasting drawing and writing have demonstrated differing outcomes. Tirre, Manelis, and Leicht (1979) contrasted drawing and writing using topics from mammalogy and archeology. The researchers extracted word groups from each topic area (i.e., "beaver, muskrat, round-tailed water rat"). Participants read the learning materials and were asked to either draw or write an explanation of the main ideas in each word group and their relationship. Participants who wrote their explanations were found to perform better on assessments that tested students on recognition and explanation items about the relationships between keywords. However, it is unclear if this indicates a general advantage for writing or whether some concepts (e.g., abstract relationships) simply are difficult to draw.

Linden and Wittrock (1981) studied writing and drawing as methods to increase reading comprehension scores. This classroom-based experiment explored differences in learning following instructions to either draw or write a summary immediately after reading stories. Compared to students who did not generate a representation (a drawing or summary), the generative conditions (i.e., draw-then-write or write-then-draw) demonstrated more relevant drawings and writing than students who received no instructions about generating representations or who did not generate a representation. This study found no differences in learning outcomes depending upon the sequence of generative activities, suggesting that the type of generation (drawing versus writing) in which students engage does not matter.

In a study that demonstrated benefits of both writing and drawing, Gobert and Clement (1999) looked at conceptual understanding in the domain of plate tectonics. The fifth graders were assigned to one of three conditions: 1) read text (control); 2) read the text and draw diagrams; 3) read the text and write summaries. Results demonstrated that the summary condition included more factual information in their representations. However, the drawing condition performed better than the writing condition on a posttest that contained short-answer items, multiple-choice questions, and a diagram task. These findings provide evidence that the type of generation (visual versus verbal) may influence students' depth of processing during learning. When writing a summary, students may be remembering facts and details. In contrast, creating an accurate diagram requires the use and modification of prior knowledge resulting in an integrated and coherent representation.

These three studies demonstrate the variability in findings across the research literature when using either writing or drawing as a learning strategy. Part of this discordance may be attributed to the assessment methods used in each study. Van Meter and Garner (2005) criticized the Tirre et al. (1979) study results due to a mismatch between the drawing learning strategy and the focus of the assessment items on abstract concepts. The Linden and Wittrock study (1981) demonstrated increased comprehension from generating multiple representations when reading text, but did not differentiate between benefits associated with drawing versus writing. In the case of the Gobert and Clement (1999) study, assessments measured multiple forms of learning outcomes and may highlight that drawing facilitates different types of comprehension processing compared to writing. In this study, the drawing participants performed better on assessments measuring deeper comprehension whereas writing participants performed better on assessments targeting memory for factual content. In the next section, there is a brief review of comprehension process levels and associated knowledge outcomes.

1.2 Comprehension Processes and Levels of Knowledge

Understanding the impact of generative strategies on learning outcomes requires attention to the comprehension processes by which learners construct knowledge. Kintsch (1991, 1993, 1998) and van Dijk and Kintch (1983) described a cyclical comprehension process called the Construction-Integration (CI) model. Focused on reading, the lowest level of comprehension in this model is the surface structure. The surface structure represents detailed memory for the exact words, sentences, and phrases within the text (i.e., the exact words in the specific order that they appeared).

The textbase representation (van Dijk & Kintsch, 1983; for additional explanations see Groen & Patel, 1988) facilitates basic recall of the meaning of text, typically in the form of propositions drawn from the text. Textbase learning is assessed via questions that focus on memory for the main points of a test. These questions often take the form of multiple choice questions (McNamara & Kintsch, 1996) or short answer questions (Gadgil et al., 2012) and depends on question phrasing.

The situation model representation is formed by the integration of prior knowledge with new knowledge (Groen & Patel, 1988; Kintsch, 1994; van Dijk & Kintsch, 1983); thus, the situation model requires transformation rather than reproduction of the text. The situation model reflects deeper understanding of a text in the context of prior knowledge; this representation is flexible, transferrable, and lasts for long periods of time. The situation model is similar to a mental model (Graesser & Forsyth, 2013) or a working model of text (Sternberg & Sternberg, 2012). To clarify meaning in the current study, the term “mental model” is used here to describe a learners’ general understanding or broad knowledge of the heart and circulatory system while the term “situation model” is used to refer to the meaningful understanding gained from materials provided during learning.

To gauge development of the situation model of text, assessment questions must require the learner to generate “why” explanations in the form of causation (Graesser & Forsyth, 2013). McNamara and Kintsch (1996) found open-ended questions to be a more sensitive measure than multiple-choice questions.

Drawing versus writing may facilitate different levels of text processing during study. When writing an essay during study, students may focus on reproducing (but not transforming) provided text content, facilitating learning at the textbase level. With drawing, participants must transform and integrate text content into a single, coherent visual representation. This transformative and integrative processing may lead to deeper understanding of the material at the level of the situation model.

1.3 The Effect of Task Instructions on Learning

The degree to which students focus on processing relevant to textbase versus situation model development may depend upon the depth or type of processing expected for each task (Hand, Prain, & Yore, 2001; Leopold & Leutner, 2012). Thus, instructions to students that focus them on different learning goals may be especially important to predicting outcomes.

When we ask students to produce a summary of learning materials, we are asking for a global or generalized description of processes or facts resulting in a focus on replicating explicitly stated text (Leopold & Leutner, 2012; McNamara & Kintsch, 1996). To complete this task the student selects important material (Friend, 2001) that describes basic knowledge that is often what teachers expect to see (Hand et al., 2001). A study done by Gobert and Clement (1999) demonstrated that when students were asked to summarize materials, they tended to provide paraphrased responses. As a result of the rote style processing in which students engage during summarizing, comprehension and transfer have been seen to decrease with summary writing (Leopold & Leutner, 2012).

In contrast, explanations require integration of knowledge across contexts through use of cause and effect rational as one must ask who, what, when, and where (Hand et al., 2001; for an additional explanation see Mayer, 1996). Explanations allow the student to focus on what they feel is important, requiring an understanding of causality relationships contained within the learning materials (Hand et al., 2001). Hand et al. (2001) demonstrated that explanations require integration of learning materials; thus, providing students with a goal to explain may spur them to engage in deeper processing during learning. When students are actively involved in integrating new and old content, they may be more likely to analyze and assess their own thinking. Thus, learning strategies that facilitate integration may be expected to promote metacognitive processing during study.

1.4 Metacognition

Metacognition can be described as the evaluation and judgment of one's cognitive strengths and weaknesses; this skill is a valuable tool for self-evaluation during learning (Berthold, Nückles, & Renkl, 2007; Flavell, 1979; Kornell & Bjork, 2008; Tanner, 2012;

Veenman, Van Hout-Wolters, & Afflerbach, 2006). Metacognitive statements can help learners identify knowledge gaps, increasing their ability to accurately identify areas for focused study (Naug, Colson, & Donner, 2011), but they can also be used to indirectly assess the learning process (Van Meter, 2001). Having the learner generate representations improves comprehension accuracy monitoring (Redford, Thiede, Wiley, & Griffin, 2012) as well as the production of clear, affirmative, and constructive monitoring statements (McCrindle & Christensen, 1995).

A study that demonstrated the use of metacognitive activities to promote deeper understanding and evaluation of learning was done by McCrindle and Christensen (1995). This study looked at learning outcomes of college biology students using writing coupled with metacognitive prompts. Compared to students who were not provided with metacognitive prompts, students who were asked to reflect and explain their learning used strategies such as drawing diagrams and relating their original theories to new materials presented in the biology text. These results suggest close ties between drawing as a learning strategy, integrative learning processes, and effective metacognition.

In an effort to separate the effects of metacognitive and cognitive prompts during learning, Berthold, Nückles, and Renkl (2007), asked undergraduate participants to write a summary about what they learned from videotaped presentations. Participants were randomly assigned to one of four groups: 1) no prompts; 2) metacognitive prompts only; 3) cognitive prompts only; 4) metacognitive and cognitive prompts (mixed prompts). Cognitive prompts included organizational and elaboration questions while the metacognitive prompts encouraged monitoring. The participants in the cognitive and mixed prompts conditions used cognitive learning strategies more than the no prompts condition. The same pattern was seen with the metacognitive prompts and mixed conditions using more metacognitive strategies than the no prompts condition. The participants that received only the metacognitive prompts or no prompts had similar scores on cognitive strategies and understanding. Thus, using metacognitive prompts alone did not result in a change in learning outcomes. Accordingly, this study uses a Berthold et al. (2007) metacognitive prompt to assess monitoring processes during study.

1.5 The Current Study

The current study attempted to investigate the impact of generating different representational formats (draw vs. write) in combination with varied task instructions (summarize vs. explain) on students' learning outcomes following study of a scientific text. The science topic was the heart and circulatory system; this topic was chosen because it is highly concrete and its cause-effect relationships can be expressed visually (e.g., in a diagram).

Drawing requires the participant not only to attend to the described structures but also to consider cause-and-effect relationships in order to correctly combine each individual structure into a coherent whole. Due to the need for integrating material in this manner, it was expected that drawing a diagram would result in the use of deeper learning strategies such as integration and elaboration. Because writing proceeds in a temporal manner, it was expected that the written representation (by itself) would not facilitate integration in a similar manner.

Task instructions, summarizing versus explanation, can be used to prioritize different levels of processing. During summarization, the participant is able focus on reproducing the information learned without needing to modify or transform the learned materials. When asked to explain a text, participants should focus on causal explanations and relationships that facilitate integration. Because drawing a diagram already requires this type of integration (due to the construction of a coherent, single representation), it was not expected that instructions would impact learning when students were producing a diagram representation. However, it was expected that task instructions would influence the learning outcomes of students producing a written representation.

Overall, an interaction was predicted such that both drawing conditions would outperform the writing + summary condition on deep-level assessments: the mental model, loop, and knowledge inference assessments. There was not expected to be a difference between the drawing conditions and the writing + explanation condition. The declarative knowledge scores were hypothesized to demonstrate the opposite pattern: the writing + summary condition would outperform the drawing conditions and the writing + explanation condition (with no differences between the drawing conditions and the writing + explanation condition).

CHAPTER 2

METHODS

2.1 Participants

Participants were drawn from the Department of Educational Psychology's undergraduate subject pool and recruited from the main campus of the University of Utah. Participants from the subject pool were concurrently enrolled in an educational psychology course and received partial credit through an introductory educational psychology class. Recruitment of paid subjects was through postings on campus bulletin boards and flier handouts. A total of 87 students were recruited for the study: 57 from the subject pool and 30 paid subjects. Of the 87, four were dropped from analysis because they did not answer the posttest assessments, resulting in incomplete data. Two were excluded due to high prior knowledge. Due to high levels of prior knowledge in science, 10 engineering majors were excluded from the sample. The remaining 71 participants were analyzed. The mean age of participants was 24.76 years and the percentage of female students was 76.1%. Junior and senior level participants composed 71.8% of the sample with 64.8% declaring an education major.

2.2 Research Design

The experiment used a between-subjects 2 (draw versus write) x 2 (summarize versus explain) factorial design. Sixteen students were assigned in the draw/explain condition, 16 served in the draw/summary condition, 20 in the write/explain condition, and 19 in the write/summary condition.

2.3 Materials and Instruments

2.3.1 Learning Module

Learning materials on the heart and circulatory system used by Gadgil et al. (2012) were adapted to create a learning module in Adobe Authorware. Taken from a college-level Biology textbook (Shier, Butler, & Lewis, 2006), the 72-line (1302 words) text described the heart anatomy, function of the valves, and blood flow (see Appendix A). Each condition used the same learning materials with the material presented one line at a time; the participant controlled the pace of presentation. After each section of text, the participant was asked to create/update a representation as relevant to their condition (draw vs. write). No diagrams were provided in the text materials to ensure the participant generated their own mental models rather than relying on author or researcher generated representations.

2.3.2 Representation Tools

All participant essays were written in Microsoft Word. All drawings were generated by participants using SketchBook Pro software on Wacom Intuos Drawing Tablets.

2.3.3 Demographic Questionnaire

A demographic questionnaire was used to collect basic information about participants, including gender, age, ethnicity, first language, and major.

2.3.4 Pretest

A pretest drawn from Gadgil et al. (2012) was used to assess participants' prior knowledge about the heart and circulatory system. The pretest included three measures, described below. All conditions received the same pretest.

2.3.4.1 Mental Model Questions

This assessment consisted of six short-answer questions about the heart and circulatory system used in previous research (Gadgil et al., 2012). Questions were presented in a single line with a textbox to enter an answer. These questions assessed the participant's initial mental model and existing knowledge of the topic. A question example was: 'Describe in a few lines the path of the blood in the circulatory system'. Each idea unit was assigned a point value; relevant idea units varied across questions, with each question being worth between one and four points. The maximum score on mental model questions was 20 points (see Appendix B for a full list of questions and the coding rubric).

2.3.4.2 Loop Assessment

The overall mental model demonstrated by students was also assessed via a loop assessment, as in Gadgil et al. (2012). Participants' responses to the first mental model question, 'Describe in a few lines the path of the blood in the circulatory system', was coded using idea units. This question was used to determine the participants' initial concept of the heart and circulatory system. The idea units used for scoring indicated whether there was a description of circulation path from the heart to the body, body to the heart, heart to the lungs, and lungs to the heart (see Appendix C for the coding rubric).

Idea units were used to categorize students into levels of understanding; these levels range from 1 – 5 with the lower category indicating a correct description of circulation and a higher scores indicating the less sophisticated understanding of the heart and circulatory system. As the direction of this scoring was opposite of other assessment scoring, the ranking was reversed for final analysis and presentation such that a score of 1 indicated the least knowledge and a score of 5 indicated the highest knowledge.

2.3.4.3 Declarative Knowledge Assessment

The declarative knowledge questions from the Gadgil et al. (2012) study were used to measure factual, text-based knowledge. The declarative knowledge assessment contained 12 terms specific to the heart and circulatory system that the participant was asked to define. The declarative knowledge questions also provided a text box for entry of the answer; however, there were five prompts listed above the textbox to help students write a complete answer (i.e., What is it? What kind of thing is it? What does it refer to? Where is it found in the body? What is its structure, texture, or composition? What does it do? What are its defining features?). For example, a pretest definition for the aorta was:

1. It is a valve;
2. It is found in the heart.

This pretest response did not receive any points. The posttest aorta definition had more idea units:

1. The aorta is an artery;
2. It is connected to the left ventricle of the heart;
3. No answer [*sic*];
4. The aorta sends the newly-oxygenated blood out into the body through the systemic circuit;
5. It is not unlike the pulmonary artery in that is sends blood from the heart.

The posttest answer was awarded the maximum idea units (2 points) because the participant defined the aorta as the main artery (1 point) that leaves the heart (.5 point), and carries oxygenated blood (.5 point). The score for each definition was either one or two points with a maximum score of 22 points (see Figure 2.1 for example; see Appendix D for a full list of questions).

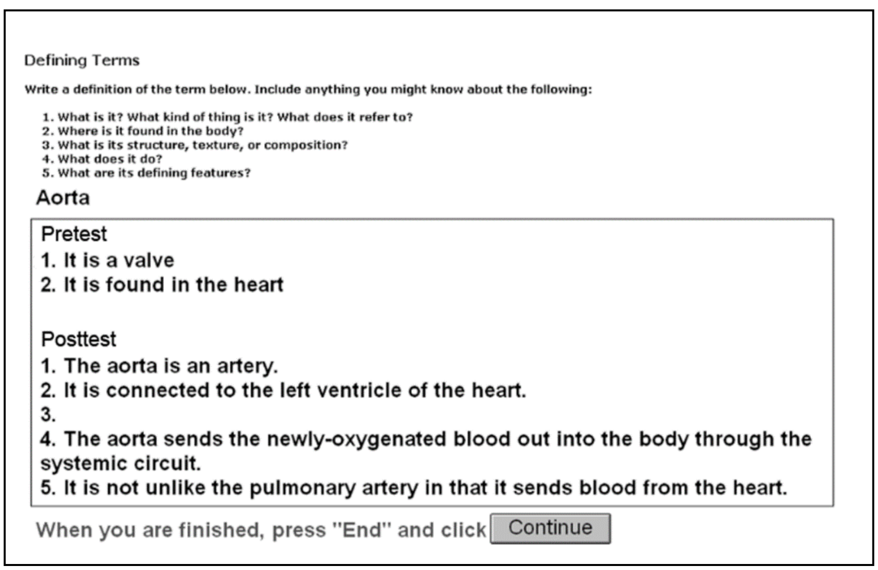

Figure 2.1. Screen shot of declarative knowledge answer for a participant in the draw/summary condition.

2.4 Drawn and Written Representations

Each participant created four representations, three while learning about the heart and circulatory system, and one after the posttest assessments. The text in the learning module was divided into three sections with 23 lines for the first and third sections and 26 lines in the second section; participants generated a representation after reading each section. Upon completion of the posttest assessments (mental model, declarative knowledge, and knowledge inference), the participant then created a final representation that was the opposite representation type (with the same task instructions) to their originally assigned representation condition (i.e., participants who originally had been assigned to one of the writing conditions completed a drawing as their final representation).

2.4.1 Representation Scoring

A rubric was developed to code the representations to allow for scoring of all the participant-created representations. The idea units were categorized into groups by factual details, function/path, terminology, and structure. An example of a factual detail would be a fact-base piece of information such as ‘the heart is 14 centimeters long’. The function/path category would indicate either how the heart and circulatory system works or the path of the blood flow. A function idea unit would be ‘the right atrium receives blood from the body’ while a path would be ‘blood moving from the right atrium to the right ventricle’. Structure idea units allowed scoring of anatomic relationships of the heart chambers, valves, septum, and vessels size relate. For example, a structure idea unit would be ‘the heart has four chambers’. The terms category scored on the usage of anatomic terms such as atrium and ventricle. The scoring categories were used because they could be used with either a drawing or essay.

As only a third of the content was presented when the participant was asked to create their first representation, only the idea units presented in that section of the text were used for scoring the first representation. The second representation was based on the first two sections of text; thus, the idea units of the rubric pertaining to content in the first two sections of text were used to score the second representation. The score for the third and opposite representation included all idea units of the rubric (for an example, see Figure 2.2). Maximum points for these sections was 28 for the first representation, 40 for the second representation, and 46 points for the third representation and the final (opposite) representation.

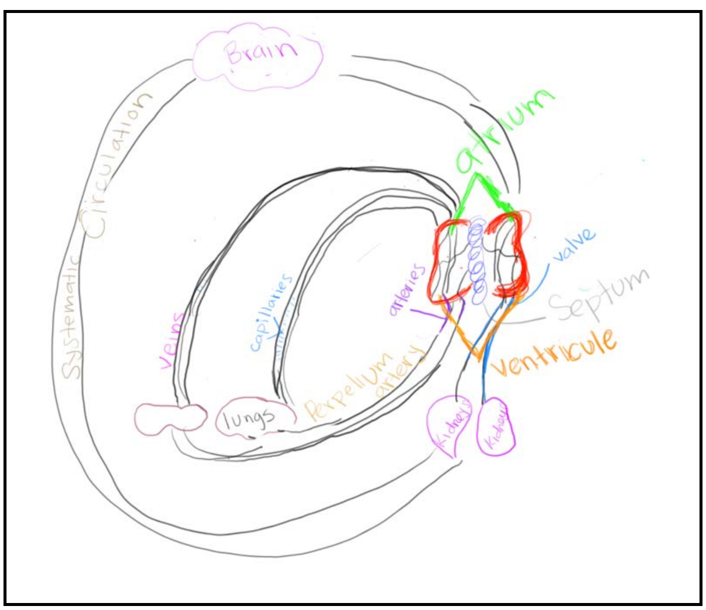

Figure 2.2. An example of an opposite representation drawn by a participant in the write/explain condition.

Similar to the loop scoring of the mental model responses, the representations were scored for idea units using a rubric developed by Chi, de Leeuw, Chiu, and Lavancher (1994). The rubric had six categories with a higher score indicating a less accurate mental model and a low score indicating a more accurate mental model (see Appendix E for the coding rubric). This coding was reversed for analysis and presentation to remain consistent with other measures (e.g., 1 = low accuracy; 6 = high accuracy).

2.5 Metacognitive Prompts

A prompt from Berthold et al., (2007) study was used to assess metacognitive thinking during learning. The prompt used was “Which main points haven’t I understood yet?” The use of this prompt allowed for assessment of the student’s metacognitive monitoring behaviors.

A unique content-based coding rubric was developed for the metacognitive statements. Statements pertaining to terminology, structures, and function and path understanding were coded to determine the type of participant monitoring occurring. Additionally, a fourth category, other, was used to code statements that did not fit into any of the preceding categories. Each participant was coded in this category and could be scored for only one monitoring type. A statement, such as ‘I am still not sure of the technical names’ would be awarded a point in the terminology category as the participant indicated a lack of knowledge in this area. The structure category was defined as a statement indicating a lack of understanding pertaining to arrangement, relations, or organization of anatomy. For example, ‘I am still unsure of how the different chambers and sections of the heart are connected' would be scored in this category. A statement such as 'What role do the lungs play in the circulatory system?' indicates a lack of understanding of the biochemical or mechanical processes that result in a specific outcome and would be scored in the function/path understanding category. The other category was for statements such as 'Blood is life!' that do not fit into any of the other monitoring types. Each statement was awarded one point with totals dependent on the number of statements the participant provided (see Appendix F for the coding rubric).

2.6 Posttest

The posttest materials included the same assessments used in the pretest (mental model, loop, and declarative knowledge), and a knowledge inference assessment. All conditions completed the same posttest.

2.6.1 Mental Model Questions

These were the same six short-answer mental model questions about the heart and circulatory system used in the pretest.

2.6.2 Loop Assessment

All participants' idea-units were scored to categorize loop understanding using the same methods as described for the pretest.

2.6.3 Declarative Knowledge Assessment

All conditions were scored for their declarative knowledge the same as the pretest.

2.6.4 Knowledge Inference Assessment

In addition to the mental model, loop, and declarative knowledge tests given at pre- and posttest, an assessment was given to evaluate the participants ability to make new connections or inferences about information provided in the learning materials. In this assessment, questions were asked relating to information not provided directly in the learning materials that required participants to reason using their mental model to reach a conclusion. For example, the answer to one question 'Why are the walls of the ventricles thicker than the atrial walls?' is never explicitly stated in the learning material.

The coding rubric developed by Gadgil et al. (2012) was used to score the idea units for the knowledge inference assessment. The knowledge inference assessment used questions 6 – 18 from the Gadgil et al. (2012) study as the answers to questions 1 – 5 were found in the learning text. The maximum score for the inference assessment was 17 points (see Appendix G for the full list of questions and the coding rubric).

2.7 Experimental Procedure

To begin the study, students completed an informed consent and were assigned a (random) numerical identifier. Participants were assigned randomly to one of the four experimental conditions. All conditions had a short training session with SketchBook Pro and the Intuos drawing tablet to familiarize them with tablet functions and digital drawing program.

Each participant then completed the demographics questions and the pretest assessments. Following the pretest, participants learned about the normal adult human heart and circulatory system using the learning module presented on a desktop computer.

The student clicked a button with an arrow to move to the next screen. After the 23rd sentence, the participant was asked to create their first representation (drawing or essay). After completing the task, the student was asked the metacognitive question pertaining to what they did not understand, entering their answer into a textbox. Upon completion, the student returned to reading the learning material, one line at a time until the 49th sentence. At this point, the student was asked to revise the first representation using the material from the second section of text. After the revision, the student was asked the same metacognitive question. The same process occurred after the final sentences (at line 72). At each of the two representation points within the text and for the third representation at the end of the text, the participant received one of the following task instructions depending on their condition.

> *Write a summary*: Thinking back to what you just read, please *write* a summary of everything you have learned from the text. The *text* that you *write* should describe the important information about the structure and function of the circulatory system as clearly as possible. Be sure your text summarizes all the important **details** that another learner would need to **remember** about this topic.
>
> *Write an explanation*: Thinking back to what you just read, please *write* an explanation of everything you have learned from the text. The *text* that you *write* should explain the important information about the structure and function of the circulatory system as clearly as possible. Be sure your text explains all the important **ideas** that another learner would need to **understand** about this topic.
>
> *Draw a summary*: Thinking back to what you just read, please *draw* a summary of everything you have learned from the text. The *diagram* that you *draw* should

describe the important information about the structure and function of the circulatory system as clearly as possible. Be sure your diagram summarizes all the important **details** that another learner would need to **remember** about this topic.

Draw an explanation: Thinking back to what you just read, please *draw* an explanation of everything you have learned from the text. The *diagram* that you *draw* should explain the important information about the structure and function of the circulatory system as clearly as possible. Be sure your diagram explains all the important **ideas** that another learner would need to **understand** about this topic.

All conditions answered the posttest questions by typing their responses in a free-form text box within the learning module. Each participant created an opposite representation (i.e., drawing will write an essay) upon completion of all learning materials and assessments. Task instructions did not change (i.e., a write + summary participant drew a summary).

The final portion of this study contained time for debriefing. The participants received credit or payment for participating in the study and were given the opportunity to ask questions about the study.

CHAPTER 3

RESULTS

3.1 Statistical Analysis

A repeated measures multivariate analysis of variance (RM-MANOVA) was conducted on the dependent variables (mental model, loop, declarative knowledge, and representation data). A univariate analysis of variance (ANOVA) using two levels of representation (draw, write) and two levels of task instructions (summary, explain) was used to analyze the knowledge inference data. For all analysis, main effects and interactions of the independent variables (representation and task instructions) were examined with conclusions based on a standard alpha level of .05. Interrater reliability was performed by two raters on 20% of the data. Agreement on continuous variables was assessed by intraclass correlations. Intraclass correlations were very high, ranging from .88 to 1.0 (see Table 3.1). Agreement on categorical loop scores was assessed by weighted Cohen's Kappa; agreement was excellent ($\kappa = .95$). Categorization of metacognitive statements also was assessed by Cohen's Kappa; these scores showed substantial agreement ($\kappa = .85$).

Table 3.1 Intraclass correlations for representation scores.

	Representation 1	**Representation 2**	**Representation 3**	**Opposite Representation**
Fact	.86	.96	.78	.88
Function/Path	.94	.96	.95	.90
Structure	.98	.98	.97	.89
Term	1	.93	.94	.98

3.2 Results

3.2.1 Mental Model Questions

The 2 (draw, write) x 2 (summary, explain) RM-MANOVA demonstrated a statistically significant difference in mental model scores for representation type ($F_{(1, 67)}$ = 6.937, p = .01, η^2 =.094), where the write condition (M = 11.7, SD = 3.67) scored higher than the draw condition (M = 9.22, SD = 4.07) on mental model questions (see Figure 3.1). There was no main effect of task instructions ($F_{(1,67)}$ <1). The two-way interaction of representation type and task instructions and time was not significant ($F_{(1, 67)}$ = 4.04, p = .21, η^2 =.023). The three-way interaction of representation type and task instructions and time was also not significant ($F_{(1,67)}$ <1).

It was hypothesized that the draw participants would score higher on the mental model assessment than the write + summarize participants but not the write + explain participants. However, this was not the case. Results demonstrated that all students who wrote during learning – regardless of whether they wrote summaries or explanations –

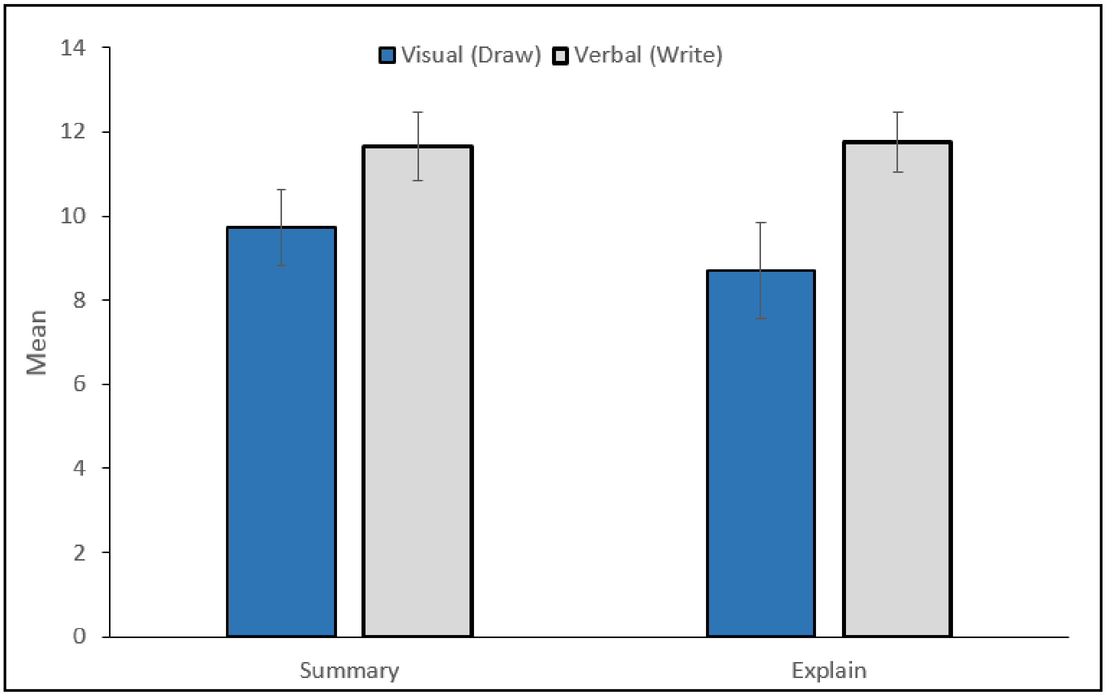

Figure 3.1. Mean scores on the mental model assessment questions by condition. Error bars represent standard error of the mean.

achieved higher mental model scores. It also was hypothesized that the write + explain participants would have a higher score than the write + summary participants on the mental model assessment; however, no difference was found.

3.2.2 Loop Assessment

The 2 (draw, write) x 2 (summary, explain) MANOVA demonstrated a statistically significant difference in loop scores for representation type ($F_{(1, 67)} = 4.994$, $p = .029$, $\eta^2 = .069$), such that the write condition ($M = 3.79$, $SD = 1.45$) scored higher than the draw condition ($M = 3.06$, $SD = 1.66$) on overall mental model loop understanding (see Figure 3.2). There was no main effect of task instructions on loop scores ($F_{(1, 67)} = 3.906$, $p = .052$, $\eta^2 = .055$). The two-way interaction between representation and task

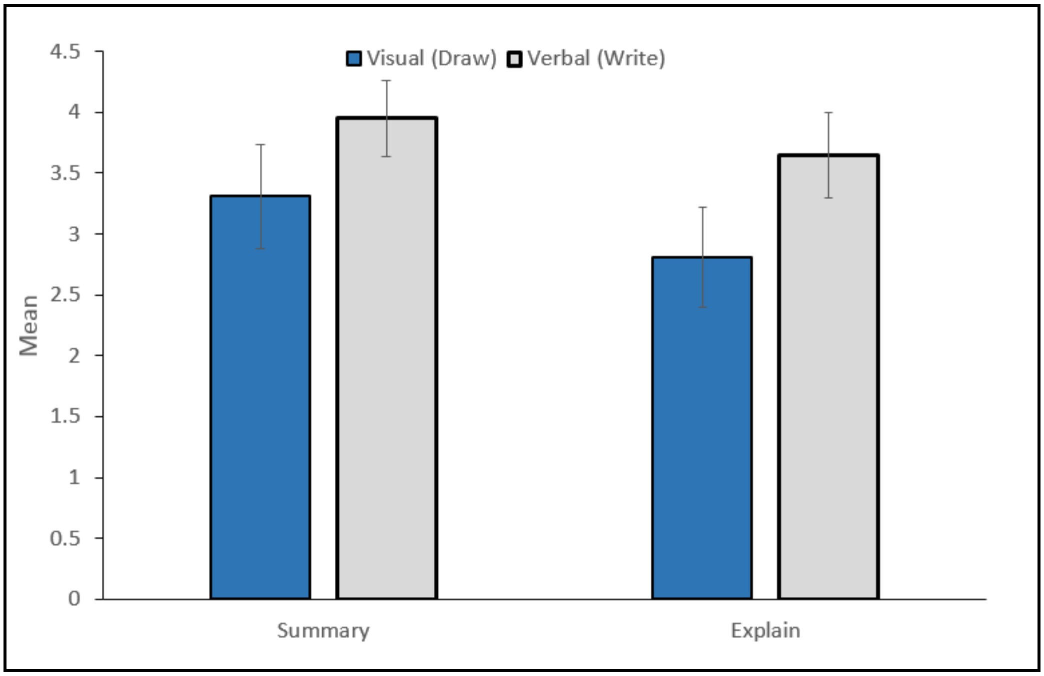

Figure 3.2. Mean loop assessment scores by condition. Error bars represent standard error of the mean.

instructions was not significant ($F_{(1, 67)} < 1$) (Figure 3.2). The three-way interaction between representation type, task instructions, and time was also not significant ($F_{(1,67)}$ <1).

As with the mental model posttest scores, it was hypothesized that draw participants would score higher on the mental model assessment than the write + summarize participants but not the write + explain participants. Results show that write participants, regardless of task instructions, achieved higher loop scores than participants who drew during study. It was also hypothesized that the write + explain participants instructions was not significant ($F_{(1, 67)} < 1$) (Figure 3.2). The three-way interaction for between representation type, task instructions, and time was also not significant ($F_{(1,67)}$ <1).

As with the mental model posttest scores, it was hypothesized that draw participants would score higher on the mental model assessment than the write + summarize participants but not the write + explain participants. Results show that write participants, regardless of task instructions, achieved higher loop scores than participants who drew during study. It was also hypothesized that the write + explain participants would have a higher score than the write + summary participants; however, results show that task instructions did not influence loop scores.

3.2.3 Declarative Knowledge Assessment

The 2 (draw, write) x 2 (summary, explain) RM-MANOVA demonstrated a statistically significant main effect of representation on declarative knowledge scores ($F_{(1, 67)} = 4.46$, $p = .039$, $\eta^2 = .062$), such that the write condition ($M = 9.35$, $SD = 4.72$) scored higher than the draw condition ($M = 7.78$, $SD = 3.97$) on declarative knowledge items (see Figure 3.3). There was not a main effect of task instructions ($F_{(1, 67)} < 1$). The two-way interaction between representation and task instructions was not significant ($F_{(1, 67)} < 1$). The three-way interaction of representation type, task instructions, and time was also not significant ($F_{(1,67)} < 1$).

If the instructions to summarize versus explain were effective, participants who were asked to summarize the learning materials should have prioritized textbase learning versus situation model development. Thus, one would expect that students in the write + summary condition should have higher declarative knowledge scores compared to students in the write + explain condition (where situation model development should have been prioritized over textbase encoding). To test this hypothesis (that the write + summary condition would have higher declarative knowledge scores than the write +

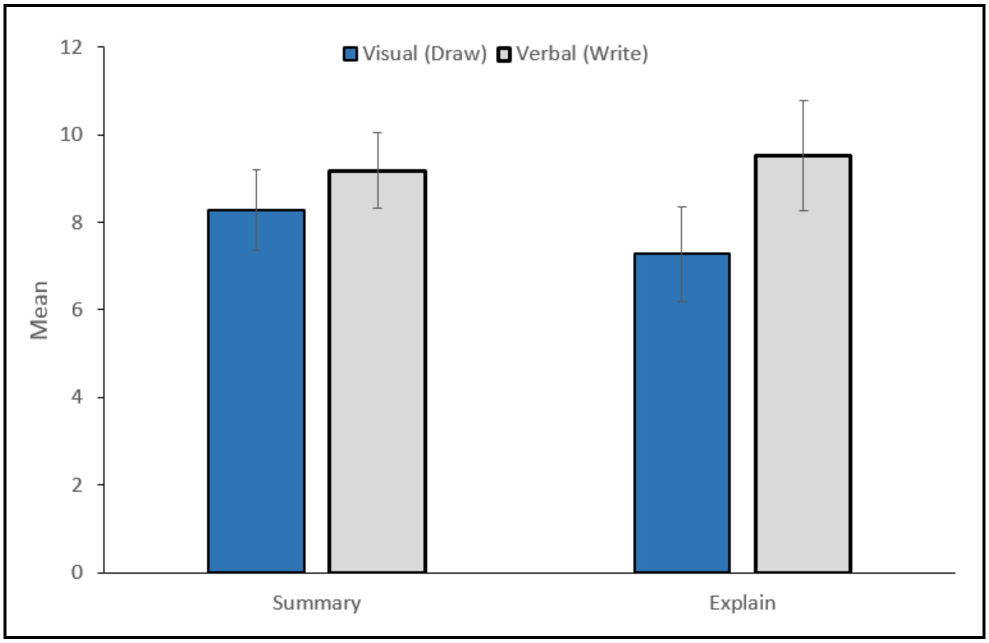

Figure 3.3. Mean scores on the declarative knowledge assessment by condition. Error bars represent standard error of the mean.

explain condition), a one-way ANOVA was performed on the subset of students who wrote during learning using task instructions (summary, explain) as the independent variable and declarative knowledge scores as the dependent variable. There was not a significant main effect of task instructions ($F_{(1, 37)} < 1$) on the declarative knowledge scores of students who wrote during learning.

All students who wrote during study, regardless of task instructions, showed stronger declarative knowledge than students who drew during study. It was hypothesized that the write + summary participants would have a higher score than the write + explain participants as well as all students who drew. This hypothesis was only partially supported; all students who wrote had higher declarative knowledge scores than students who drew during learning. However, results show that task instructions did not influence declarative knowledge scores among students who wrote during learning.

3.2.4 Knowledge Inference Assessment

The knowledge inference assessment scores (posttest only) were analyzed with a 2 X 2 analysis of variance (ANOVA). There were two levels of representation (draw, write) and two levels of task instructions (summary, explain). There was no main effect of representation ($F_{(1, 67)} = 2.693$, $p = .10$, $\eta^2 = .039$) or task instructions ($F_{(1, 67)} < 1$), nor was there an interaction between representation and task instructions ($F_{(1, 67)} = 2.631$, $p = .10$, $\eta^2 = .038$).

The draw participants were expected to score higher than the write + summary condition on inferential measures. Additionally, the write + explain condition was hypothesized to outperform the write + summarize condition on inferential processing. These hypothesis were not supported; there were no significant differences in knowledge inference scores. For this measure, the low overall scores indicate a lack of deep knowledge and inference development regardless of condition.

3.2.5 Student-Generated Representations

A 2 (draw, write) x 2 (summary, explain) RM-MANOVA on the representation data showed no main effects of representation ($F_{(1, 67)} < 1$) or task instructions ($F_{(1, 67)} < 1$). The two-way interaction between representation and task instructions was not significant ($F_{(1, 67)} < 1$). There was not a significant three-way interaction between representation, task instructions, and time ($F_{(1, 67)} < 1$). Although draw participants were expected to score higher than the write + summary and the write + explain condition, this hypothesis was not supported.

The loop scores for representations demonstrated a trend ($F_{(1, 67)} = 3.86$, $p = .054$,

η^2 = .054), such that the write condition (*M* = 3.08, *SD* = 1.74) scored higher than the draw condition (*M* = 2.67, *SD* = 1.44). However, this trend did not quite reach the level of statistical significance. There was not a main effect of task instructions ($F_{(1, 67)} = 1.68$, $p = .199$, $\eta^2 = .25$). The two-way interaction between representation and task instructions was not significant ($F_{(1, 67)} < 1$). The three-way interaction between representation, task instructions, and time was not significant ($F_{(1, 67)} < 1$). The draw participants were expected to score higher on the loop idea units than the write + summary and write + explain participants; however, the opposite trend was found. Overall, the write condition scored higher than the draw condition regardless of task instructions. Low overall scores for both the representation and loop scoring indicate a lack of overall understanding in all conditions.

Independent-samples *t*-tests were conducted to compare the number of factual and inference-based idea units used by participants according to representation and task instruction conditions.

3.2.5.1 Factual Idea Units

There was not a significant difference ($t_{(69)} = -1.728$, $p = .088$) in the number of factual idea units scored for draw (*M* = 5.78, *SD* = 6.433) and write (*M* = 8.24, *SD* = 5.57) conditions. There also was not a significant difference ($t_{(69)} = 1.536$, $p = .129$) in number of factual idea units when comparing the summary (*M* = 8.24, *SD* = 6.89) and explain (*M* = 6.0, *SD* = 4.97) conditions.

If instructions to summarize a set of learning materials encouraged students to emphasize textbase encoding during learning, the write + summary condition should demonstrate higher scores for factual idea units when compared to students who were asked to write a deeper explanation. To test this possibility, a follow-up *t*-test was performed. For participants in the write conditions, task instructions (summary, explain) did not influence the number of factual idea units included in their representation ($t_{(37)}$ = .707, p = .484).

3.2.5.2 Inferential Idea Units

There was not a significant difference ($t_{(69)}$ = -1.577, p = .12) in number of inferential idea units included in representations generated by the draw (M = 1.88, SD =2.37) and write (M = 3.33, SD = 3.33) conditions. There was also not a significant difference ($t_{(69)}$ = -.549, p = .58) in the number of inferential idea units included in representations across the summary (M = 2.4, SD = 3.59) and explain (M = 2.94, SD = 4.7) conditions.

To test the hypothesis that the write + explain condition would have higher outcomes that the write + summary condition on inferential idea units, a follow-up *t*-test was performed. For participants in the write conditions, task instructions (summarize versus explain) did not influence the number of inferential idea units included in their representation ($t_{(37)}$ = -1.018, p = .315).

3.2.6 Metacognitive Statements (Responses to Metacognitive Prompts)

A 2 (draw, write) x 2 (summary, explain) x 3 (time) RM-MANOVA did not demonstrate a main effect of representation type on metacognitive statements related to terms ($F_{(1, 67)} < 1$), function/path ($F_{(1, 67)}$ = 1.29, p = .26, η^2 = .019), structure ($F_{(1, 67)}$ =

3.391, $p = .07$, $\eta^2 = .048$), or number of irrelevant statements ($F_{(1, 67)} < 1$). No main effects of task instructions were found for terms ($F_{(1, 67)} < 1$), function/path ($F_{(1, 67)} < 1$), or structure ($F_{(1, 67)} = 1.65$, $p = .2$, $\eta^2 = .024$); however, there was a significant main effect of task instructions on the number of irrelevant statements generated by participants ($F_{(1, 67)} = 4.562$, $p = .036$, $\eta^2 = .064$). The summary condition ($M = 1.91$; $SD = 1.92$) had more extraneous (other) statements than the explain condition ($M = 1.03$; $SD = 1.38$). As seen in Figure 3.4, this main effect may have been driven by participants in the write + summary condition, who generated the largest number of irrelevant statements. A two-way interaction between representation and task instructions was not found for any measure: term ($F_{(1, 67)} < 1$), function/path ($F_{(1, 67)} < 1$), structure ($F_{(1, 67)} < 1$), or irrelevant statements ($F_{(1, 67)} = 1.075$, $p = .3$, $\eta^2 = .016$). The three-way interaction of representation type, task instructions, and time was not significant ($F_{(1,67)} <1$).

3.2.7 Quantitative Variables: Scale Interrelationships

Correlations for the dependent variables were performed. The assessments drawn from previous research (Gadgil et al., 2012) all showed significant, positive correlations with each other. Correlations between these assessments (mental model, loop, declarative knowledge, and knowledge inference) ranged from .38 (declarative knowledge and loop scores) to .71 (mental model and declarative knowledge scores) Idea unit scoring for the representations (drawn or written) also demonstrated a significant positive correlation for structure, terms, representation 3, and the opposite representation. Correlations between assessments ranged from .30 (representation 3 and terminology) to .71 (opposite representation and the function and path). There was also a

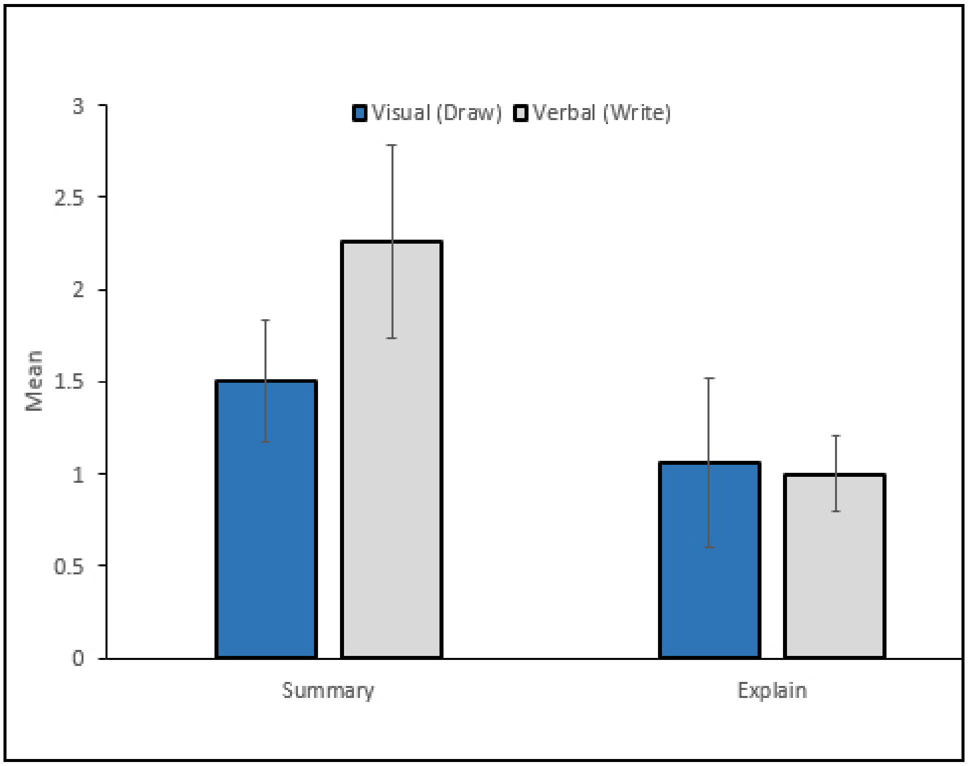

Figure 3.4. Mean number of irrelevant statements included in responses to the metacognitive self-assessment, by condition. Error bars represent standard error of the mean.

weak but significant correlation between terminology use in representations and declarative knowledge scores (.26) and the representation idea unit scores and the knowledge inference scores (.22). The correlations between dependent measures are presented in Table 3.2.

The number of extraneous (other) metacognitive statements showed a significant, negative correlation to multiple measures: mental model (-.38), declarative knowledge (-.27), representation structure (-.27), terms (-.27), loop scores for representation 3 (-.25), and metacognitive statements for function and path (-.29). This indicates fewer extraneous metacognitive statements were associated with higher scores on a number of

Table 3.2 Correlations for Dependent Variables (*N* = 71).

	Variables	1	2	3	4	5	6
1.	MM	1					
2.	Loop	.64*	1				
3.	DK	.71**	.38**	1			
4.	KI	.62*	.41**	.70**	1		
5.	Total Fact Rep	.22	.11	.13	.04	1	
6.	Total Funct/path Rep	.07	-.05	.11	.06	.31*	1
7.	Total Struct Rep	.14	-.01	.16	.18	.21	.70**
8.	Total Terms Rep	.24*	-.08	.26*	.22	.17	.62**
9.	Loop Rep 3	.15	.02	.22	.22*	.30**	.50**
10.	Loop Opposite Rep	.18	.09	.22	.17	.23	.71**
11.	Total Term Metacog	.07	.24*	.05	.07	.08	-.02
12.	Total Struct Metacog	.02	-.07	-.14	-.01	-.04	-.06
13.	Total Funct/path Metacog	-.09	-.11	.10	.06	.03	.12
14.	Total Other Metacog	-.38**	-.21	-.27*	-.21	-.05	-.18

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

MM = Mental Model assessment; Loop = Loop score for Mental Model assessment; DK = Declarative Knowledge assessment; KI = Knowledge Inference assessment;

Table 3.2 continued

	Variables	7	8	9	10	11	12	13
1.	MM							
2.	Loop							
3.	DK							
4.	KI							
5.	Total Fact Rep							
6.	Total Funct/path Rep							
7.	Total Struct Rep	1						
8.	Total Terms Rep	.58**	1					
9.	Loop Rep 3	.47**	.30**	1				
10.	Loop Opposite Rep	.58**	.57**	.43**	1			
11.	Total Term Metacog	.04	-.09	-.02	.03	1		
12.	Total Struct Metacog	-.10	-.01	.01	-.05	-.17	1	
13.	Total Funct/path Metacog	.18	.12	.18	.12	-.25*	-.22	1
14.	Total Other Metacog	-.27*	-.27*	-.25*	-.21	-.01	-.23	-.29*

Total Fact Rep = Total factual idea units for all representations; Total Funct/path rep = Total function and path idea units for all representations; Total Struct Rep = Total structure idea units for all representations; Total Terms Rep = Total term idea units for all representations; Loop Rep 1 = The loop score for the first representation; Loop Rep 2 = The loop score for the second representation; Loop Rep 3 = The score for the third representation; Loop Opposite Rep = The score for the opposite representation; Total Term Metacog = The number of metacognitive statements relating to terms; Total Struct Metacog = Total metacognitive statements relating to structure; Total Funct/path Metacog = Total of metacognitive statements relating to function/path; Total Other Metacog = Total metacognitive statements that cannot be assigned to other categories the knowledge assessments. Extraneous metacognitive statements did not pertain to the subject; as may be expected, students who spent more time “off-topic” were less likely to gain demonstrable knowledge.

CHAPTER 4

DISCUSSION

4.1 Major Findings

The study was designed to explore how representation type (draw versus write) and task instructions (summarize versus explain) influenced student learning outcomes following study of a scientific topic (the human heart and circulatory system). The major hypothesis was that drawing would encourage deeper learning by promoting integration and elaboration of the learning content during development of a single, coherent representation. In contrast, the participants in the write condition were expected to be affected by task instructions to summarize or explain. Task instructions (summarize versus explain) were expected to influence processing levels for students who generated a written representation during study. Students asked to write an explanation were expected to use deeper learning strategies and students asked to write a summary were expected to rely on superficial learning strategies.

The mental model scores, loop scores, and declarative knowledge scores showed that participants in the writing conditions scored higher than those asked to draw a diagram, regardless of task instructions. Thus, this study shows a potential advantage of writing despite previous work that has demonstrated a correlation between drawing (Ainsworth, Prain, & Tytler, 2011; Butcher & Chi, 2006; Leopold & Leutner, 2012) and the use of explanations (Applebee, 1984; Chi et al., 1994; Hand et al., 2001) in promoting deeper learning. Why does this study contradict those findings?

One possibility is that students in this study did not follow representation instructions very well. Many drawings produced by participants contained a large amount of text indicating that participants were not following instructions to draw a summary or draw an explanation (see Figure 4.1). Though they received instructions about the format of their representation a total of four times during the learning materials and the experimenter verbally reminded the participant of the representation that they were to produce, participants in the drawing condition did not stick to visual diagrams. As a result, the “drawn” representations may not have been distinct enough from written representations to show differences in learning outcomes. Future studies may need to enforce representations types more strictly, by prohibiting students in the “draw” conditions from using text other than 1-2 word labels for drawn elements.

Another consideration may lie in the amount of support provided, or not provided, to the learner. In previous studies, students frequently have been provided with reference materials to compare to their own representations. For example, a model diagram to compare to a self-generated diagram (Van Meter 2001). The current study did not provide reference or comparison materials to students, relying on students to diagnose their own representations without additional support. The results from the current study may support Alesandrini’s (1981) assertion that creating external representations does not facilitate learning unless some type of external support also is provided. Without this type of external support, students may have maintained a flawed mental model as in Butcher

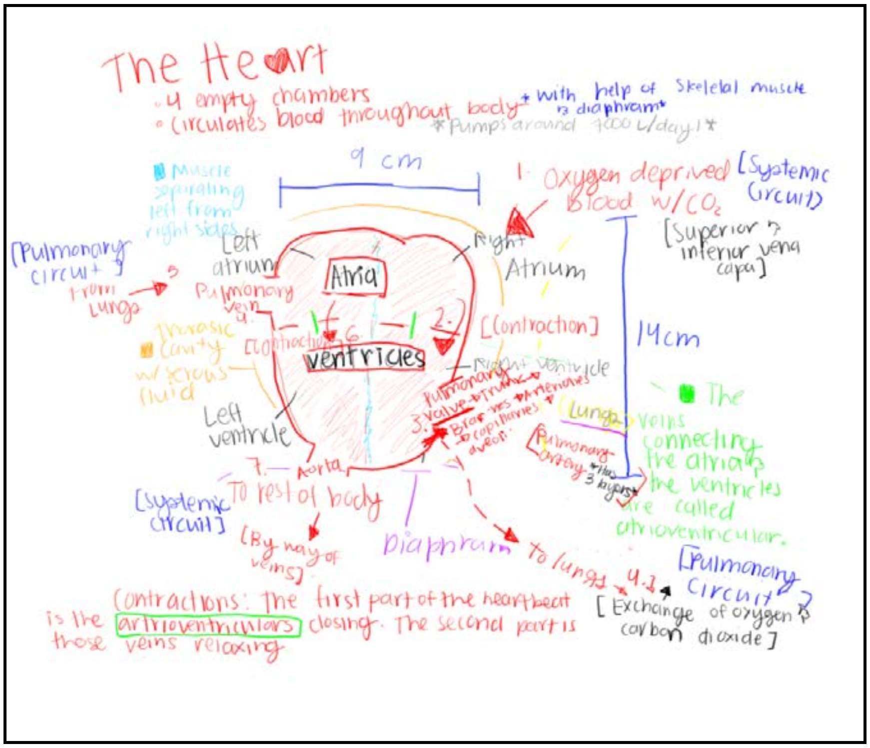

Figure 4.1. A “drawing” for a participant in the draw/summary condition showing extensive reliance on text.

and Chi’s (2006) research; this possibility is supported by overall low scores on inference measures in this research (i.e., mental model, knowledge inference) compared to higher scores for the textbase measure (i.e., declarative knowledge).

Just as the representation manipulation may not have been strong enough in this research, the manipulation of task instructions may not have been effective. The write + explain and the write + summary conditions showed no differences in the number of factual or inferential statements generated by participants. This contradicts previous research that has demonstrated that task instructions influence processing depth (Hand et al., 2001; Leopold & Leutner, 2012). Creating a summary should emphasize encoding at the textbase level, particularly at the expense of situation model development (Leopold &

Leutner, 2012). Knowledge integration should be more likely to occur when a student is asked to explain a topic because they are required to process the material through combination of new and learned materials, resulting in a more flexible and robust situation model representation (Hand et al., 2001). However, the current findings were not consistent with these predictions. A few possibilities for the current findings must be considered. First, it is possible that intervention on task instructions (summarize versus explain) were not strong enough to result in differential behaviors during learning. The major form of this intervention was a written set of instructions that differed in only a few key words. Students may not have interpreted these instructions differently, especially in the absence of practice and/or feedback. Future research should consider whether practice tasks or more intensive instruction would result in differential processing during text study when additional representations are being produced as part of the learning opportunity. Second, it is possible that summarization is essentially similar to explanation in this type of domain. That is, learning the key structures and temporal processes may be akin to understanding circulatory system functioning. For this reason, students may not be affected by instructions to summarize versus explain in this domain. Another possibility is that students lacked the prior knowledge to explain effectively, thus rendering the task instructions moot. Students may have initially needed to focus on textbase processing given a lack of prior knowledge in the domain. Future research could use pretraining or prescreening procedures to ensure a sufficient level of prior knowledge to facilitate deeper processing of the learning materials.

4.2 Theoretical Implications

The measures in this study demonstrated that participants asked to write an essay during learning scored higher on multiple measures than those asked to draw. These learning outcomes are rather inconsistent with those finding that visual methods demonstrate deeper learning (Schwamborn et al., 2010; Van Meter, 2001). It is possible that the topic area was too difficult for the participant population and, thus, they were unable to create the necessary links between prior knowledge and the new information necessary to develop deeper understanding. Indeed, scores on assessments measuring overall understanding were quite low in this study. The average mental model score was 7.78 of a maximum 20 points, and the knowledge inference scores averaged only 3 out of a possible 17. These low scores raise concern for a floor effect across study conditions.

4.3 Conclusions and Recommendations

Results from this study demonstrate that writing may be a more effective strategy for learners when additional scaffolds or support is not provided. Students who wrote summaries or explanations outperformed their peers who drew representations on measures of mental models and declarative knowledge. These findings suggest that students may find it difficult to use drawing as a study strategy. Results also demonstrated that the two write conditions (write + explain, write + summary) did not show differences in scores. Without additional training, examples, or feedback, students may not be able to understand how study strategies related to explanation differ from those related to summarization. In addition, no differences were seen in deeper understanding, regardless of condition, as scores on inference measures were quite low across all conditions. Thus, students may need more effective strategies overall in order to develop meaningful levels of knowledge that will be transferrable to new situations.

Further exploration is needed to determine whether scaffolds and supports (for example, model diagrams for comparison) could improve the potential of diagram drawing as a strategy to promote deeper learning. Another question is whether or not limiting text production during drawing would increase processing differences when visual versus verbal strategies are used during study. This study highlights the fact that learners may find it difficult to change their preferred strategies, taking numerous written notes even when asked to “draw.”

Overall, this research demonstrates that it is difficult to change learner strategies or depth of processing when studying an unfamiliar science topic.

APPENDIX A

TEXT USED FOR LEARNING SECTION

Learning Block #1

Sentence	Text
1	The heart is a hollow, cone-shaped, muscular pump.
2	The heart pumps 7000 L of blood through the body each day, contracting some 2.5 billion times in an average lifetime.
3	An average adult's heart is about 14 cm long and 9 cm wide.
4	It lies within the thoracic cavity and rests on the diaphragm.
5	The pericardium encircles the heart.
6	Between the layers of pericardium is a space, the pericardial cavity that contains a small volume of serous fluid.
7	This fluid reduces friction between the pericardial membranes as the heart moves within them.
8	Internally, the heart is divided into four hollow chambers- two on the left and two on the right.
9	The upper chambers, called atria, have thin walls and receive blood returning to the heart.
10	The lower chambers, the ventricles, receive blood from the atria and contract to force blood out of the heart into arteries.
11	A solid wall like septum separates the atrium and ventricle on the right side from their counterparts on the left.
12	The right atrium receives blood from two large veins, the superior vena cava and the inferior vena cava.
13	The large tricuspid valve, which has three tapered projections called cusps, lies between the right atrium and the right ventricle.
14	The valve permits blood to move from the right atrium into the right ventricle and prevents backflow.
15	When the muscular wall of the right ventricle contracts, the blood inside its chamber is put under increasing pressure and the tricuspid valve closes passively.
16	As a result, the only exit for the blood is through the pulmonary trunk, which divides to form the left and right pulmonary arteries that lead to the lungs.

17	At the base of this trunk is a pulmonary valve with three cusps that allows blood to leave the right ventricle and prevents backflow.
18	The left atrium receives blood from the lungs through four pulmonary veins, two from the right lung and two from the left lung.
19	Blood passes from the left atrium into the left ventricle through the bicuspid valve.
20	When the left ventricle contracts the bicuspid valve closes passively and the only exit is through a large artery, the aorta.
21	At the base of the aorta is the aortic valve, which opens and allows blood to leave the left ventricle.
22	The bicuspid and tricuspid valves are called atrioventricular valves because they are between the atria and ventricles.
23	Blood that is low in oxygen and high in carbon dioxide enters the right atrium.
Learning Block #2	
24	As the right atrial wall contracts, the blood passes through the tricuspid valve and enters the chamber of the right ventricle.
25	When the right ventricular wall contracts, the tricuspid valve closes, and blood moves through the pulmonary valve and into the pulmonary trunk and pulmonary arteries.
26	From the pulmonary arteries, blood enters the capillaries associated with the microscopic air sacs of the lungs (alveoli).
27	Gas exchanges occur between the blood in the capillaries and the air in the alveoli.
28	The freshly oxygenated blood returns to the heart through the pulmonary veins that lead to the left atrium.
29	The left atrial wall contracts and blood moves through the bicuspid valve and into the chamber of the left ventricle.
30	When the left ventricular wall contracts, the bicuspid valve closes and blood moves through the aortic valve and into the aorta and its branches.
31	A heartbeat heard through a stethoscope sounds like “lubbdupp”.
32	The first part of a heard sound (lubb) occurs during ventricular contraction, when the atrioventricular valves are closing.
33	The second part (dupp) occurs during ventricular relaxation, when the pulmonary and aortic valves are closing.
34	The blood vessels form a closed circuit of tubes that carries blood from the heart to the cells, and back again.
35	These vessels include arteries, arterioles, capillaries, venules, and veins.
36	Arteries are strong elastic vessels that are adapted for carrying blood away from the heart under high pressure.
37	These vessels subdivide into progressively thinner tubes and eventually give rise to finer, branched arterioles.
38	The wall of an artery consists of three distinct layers.
39	The innermost layer is composed of a simple squamous epithelium, called endothelium, which rests on a connective tissue membrane that is rich in elastic and collagenous fibers.

40	The middle layer makes up the bulk of the arterial wall.
41	It includes smooth muscle fibers, which encircle the tube and irregularly organized elastic and collagenous fibers.
42	The outer layer is relatively thin and chiefly consists of connective tissue with irregularly organized elastic and collagenous fibers.
43	This layer attaches the artery to the surrounding tissue.
44	Capillaries, the smallest diameter blood vessels, connect the smallest arterioles and the smallest venules.
45	Capillaries are extensions of the inner linings of arterioles in that their walls are composed of endothelium.
46	These thin walls form the semipermeable layer through which substances in the blood are exchanged for substances in the tissue fluid surrounding body cells.
47	The substances exchanged move through capillary walls through diffusion, filtration, and osmosis.
48	Venules are the microscopic vessels that continue from the capillaries and merge to form the veins.
49	The veins, which carry blood back to the atria, follow pathways that roughly parallel those of the arteries.
Learning Block #3	
50	Blood pressure decreases as blood moves through the arterial system and into the capillary networks, so little pressure remains at the venular ends of capillaries.
51	Instead, blood flow through the venous system is only partly the direct result of heart action and depends on other factors, such as skeletal muscle contraction and breathing movements.
52	Contracting skeletal muscles press on nearby vessels, squeezing the blood inside.
53	As skeletal muscles press on veins with valves, some blood moves from one valve section to another.
54	Respiratory movements also move venous blood.
55	During inspiration, the pressure on the thoracic cavity is reduced as the diaphragm contracts and the rib cage moves upward and outward.
56	At the same time, the pressure within the abdominal cavity is increased as the diaphragm presses down on the abdominal viscera.
57	Consequently, blood is squeezed out of abdominal veins into thoracic veins.
58	During exercise, these respiratory movements act with skeletal muscle contractions to increase the return of venous blood to the heart.
59	Blood vessels can be divided into two major pathways.
60	The pulmonary circuit consists of vessels that carry blood from the heart to the lungs and back again.
61	The systemic circuit carries blood from the heart to all other parts of the body and back again.

62	Blood enters the pulmonary circuit as it leaves the right ventricle through the pulmonary trunk.
63	The pulmonary trunk extends upward from the heart.
64	The pulmonary trunk divides into the right and left pulmonary arteries, which penetrate the right and left lung.
65	After repeated divisions, the pulmonary arteries give rise to arterioles that continue into the capillary networks associated with the walls of the alveoli, where gas is exchanged between blood and air.
66	From the pulmonary capillaries, blood enters the venules, which merge to form small veins, which merge to form larger veins.
67	Four pulmonary veins, two form each lung, return blood to the left atrium, which completes the pulmonary loop.
68	Freshly oxygenated blood moves from the left atrium to the left ventricle.
69	Contraction of the left ventricle forces the blood into the systemic circuit, which includes the aorta and its branches that lead to all the body tissues, as well as the companion system of veins that returns blood to the right atrium.
70	Blood signifies life, and for good reason, it has many vital functions.
71	This complex mix of cells, cell fragments, and dissolved biochemical transports nutrients, wastes, oxygen, and hormones; helps maintain the stability of interstitial fluids, and distributes heat.
72	The blood, heart, and blood vessels form the cardiovascular system and link the body's internal and external environment.

Text from: Shier, D., Butler, J., & Lewis, R. (2006). *Hole's essentials of human anatomy and physiology*. Boston: McGraw Hill.

APPENDIX B

CODING RUBRIC USED TO SCORE THE MENTAL MODEL ASSESSMENTS AT PRE- AND POSTTEST

Question	Idea Units	Points
1. Describe in a few lines the path of the blood in the circulatory system.	Heart to Lungs	1
	Lungs to Heart	1
	Heart to Body	1
	Body to Heart	1
2. What types of blood vessels are present in the circulatory system and what are their functions?	Arteries	0.5
	Carry blood away from heart	0.5
	Veins	0.5
	Carry blood back to heart	0.5
	Arterioles	0.5
	Connect arteries to capillaries	0.5
	Venules	0.5
	Connect capillaries to veins	0.5
	Capillaries	0.5
	Gas exchange	0.5
3. Describe the structure of the heart in a few lines and explain the functions of each part.	4 chambers	1
	Atria	0.5
	Upper chambers	0.25
	Receive blood from the body/lungs	0.25
	Ventricles	0.5
	Lower chambers	0.25
	Receive blood from the atrium	0.25
	Valves	0.5
	Between atria and ventricles	0.25
	Prevent backflow	0.25
	Septum	0.5
	Separates the heart down the middle	0.25
	Prevents gas mixing	0.25

4. What are important components of the circulatory system and what role do they play in circulation?	Heart Pumps blood Lungs Oxygenates blood Blood vessels (arteries/veins) Transport blood	0.5 0.5 0.5 0.5 0.5 0.5
5. What are the primary and secondary functions of blood?	Supply oxygen/nutrients to body/tissues	1
	Removing waste OR maintaining body temp	1
6. What is the main function of the heart?	Pumping/circulating blood	1
	Total possible points	20

Rubric modified from: Gadgil, S., Nokes-Malach, T., and Chi, M. (2012). Effectiveness of holistic mental model confrontation in driving conceptual change. Learning and Instruction, 22(1), 47-61. doi: http://dx.doi.org/10.1016/j.learninstruc.2011.06.002

APPENDIX C

CODING RUBRIC USED FOR SCORING THE LOOP PRE- AND POSTTEST ASSESSMENT

	Loop Categories	Question 1 path award
1	Correct Double Loop 1. All features from Partially Correct Double Loop 2. Heart has four chambers 3. Septum divides heart lengthwise-sense of preventing mixing of blood. 4. Blood flow through heart is top to bottom. 5. At least three of the following: a. Blood flows from right ventricle to the lungs. b. Blood flows from lungs to left atrium. c. Blood flows from left ventricle to body. d. Blood flows from body to right atrium.	If participant gets four points for item #1 AND uses correct direction/terminology, assign this category.
2	Partially Correct Double loop 1. Blood is primarily contained in blood vessels. 2. Heart pumps blood to body. 3. Blood returns to heart from body. 4. Heart pumps blood to lungs. 5. Blood returns to heart from lungs. 6. Lungs play a role in the oxygenation of blood.	If participant gets four points for item #1 BUT reverses (or does not specify) correct direction OR uses incorrect terminology/parts, assign this category.
3	Single Loop with Lungs: 1. Blood is primarily contained in blood vessels. 2. Heart pumps blood to body or to lungs. 3. Blood returns to heart from body or from lungs. 4. Blood flows from lungs to body or from	Participant must mention lungs; pathway is a single loop.

	body to lungs without return to heart in between. 5. Lungs play a role in the oxygenation of blood.	
4	Single Loop: 1. Blood is primarily contained in blood vessels. 2. Blood is pumped from the heart to the body. 3. Blood returns to the heart from the body.	Pathway is a single loop; no mention of lungs.
5	Other (unclassifiable): Any description that could not be classified under one of the above categories was coded as “Other.”	

Rubric modified from: Gadgil, S., Nokes-Malach, T., and Chi, M. (2012). Effectiveness
of holistic mental model confrontation in driving conceptual change. Learning and Instruction, 22(1), 47-61. doi: http://dx.doi.org/10.1016/j.learninstruc.2011.06.002

APPENDIX D

CODING RUBRIC USED FOR SCORING THE DECLARATIVE KNOWLEDGE PRE- AND POSTTEST ASSESSMENT

Term	Answer	Idea Unit/Point award	Max Point
Aorta	The main artery that carries oxygenated blood from the heart to the body.	Main artery=1 Leaves heart=.5 Oxygenated/high in oxygen=.5	2
Atrium	The upper chambers of the heart that pump blood to the ventricles.	Upper chamber=1 Pumps to ventricles=1	2
Pulmonary Artery	The artery that carries deoxygenated blood from the heart to the lungs.	Heart to lungs=1 Carries deoxygenated/low in oxygen=1	2
Septum	Tissue that divides the heart lengthwise, which separates oxygenated from deoxygenated blood.	Part of heart=1 Divides=1	2
Heartbeat	The heartbeat is the sound of the heart valves closing.	Valves closing OR ventricles contracting	1
Systemic Circulation	The movement of blood between the heart and the rest of the body.	Heart=1 Body=1	2
Ventricle	The lower chambers of the heart that pump the blood to the lungs or the body.	Lower chamber=1 To body OR lungs=1	2
Valve		Unidirectional=1	2

	Tissue that allows blood to move in only one direction. Located in the heart, veins, and artery origin.	Heart OR veins OR artery=1	
Venule	Venules are the microscopic vessels that continue from the capillaries and merge to form the veins.	Microscopic=1 Veins=1	2
Capillary	Smallest blood vessel; allows the diffusion of food, waste, and gases across the cell membrane.	Smallest blood vessel=1 Diffusion or movement of gas from one area to another=1	2
Alveoli	Alveoli are microscopic air sacs present in the lungs in which gas is exchanged between blood and air.	Air sacs=1 Gas exchange=1	2
Skeletal Muscle	Skeletal muscle are muscles that aid the return of venous blood to the heart via contraction.	Aid return of blood=1	1
		Total Possible Points	22

Rubric modified from: Gadgil, S., Nokes-Malach, T., and Chi, M. (2012). Effectiveness of holistic mental model confrontation in driving conceptual change. Learning and Instruction, 22(1), 47-61. doi: http://dx.doi.org/10.1016/j.learninstruc.2011.06.002

APPENDIX E

CODING RUBRIC USED FOR REPRESENTATION LOOP SCORING

Loop Categories

Correct Double Loop
1. Heart has four chambers
2. Septum divides heart lengthwise-sense of preventing mixing of blood.
3. Blood flow through heart is top to bottom.
4. Blood is primarily contained in blood vessels
6 5. Lungs play a role in oxygenation of the blood
6. At least three of the following:
   a. Blood flows from right ventricle to the lungs.
   b. Blood flows from lungs to left atrium.
   c. Blood flows from left ventricle to body.
   d. Blood flows from body to right atrium.

Partially Correct Double loop
1. Blood is primarily contained in blood vessels.
2. Heart pumps blood to body.
5 3. Blood returns to heart from body.
4. Heart pumps blood to lungs.
5. Blood returns to heart from lungs.
6. Lungs play a role in the oxygenation of blood.

Single Loop with Lungs:
1. Blood is primarily contained in blood vessels.
2. Heart pumps blood to body or to lungs.
4 3. Blood returns to heart from body or from lungs.
4. Blood flows from lungs to body or from body to lungs without return to heart in between.
5. Lungs play a role in the oxygenation of blood.

3	Single Loop: 1. Blood is primarily contained in blood vessels. 2. Blood is pumped from the heart to the body. 3. Blood returns to the heart from the body.
2	Ebb and flow: 1. Blood is primarily contained in blood vessels. 2. Blood is pumped from the heart to the body. 3. Blood returns to the heart by way of the same blood vessel.
1	No Loop: 1. Blood is pumped from the heart to the body. 2. Blood does not return to the heart.
Additional scoring criteria 1. Arrows indicate direction 2. Red = arterial flow 3. Blue = venous flow 4. If arrows indicate flow in/out of heart, assume flow through the heart in the same direction.	

Rubric modified from: Chi, M., de Leeuw, N., Chiu, M., and Lavancher, C. (1994). Eliciting self-explanations improves understanding. Cognitive Science, 18(3), 439-477. doi: 10.1207/s15516709cog1803_3

APPENDIX F

CODING RUBRIC USED FOR SCORING METACOGNITIVE RESPONSES

Monitor Type	Abbr	Definition	Example
Terminology knowledge	T	Statement of lack of terminology knowledge.	I am still not sure of the technical names… It introduced some words I hadn't seen before, and I had a hard time remembering them.
Structure understanding	S	Statement indicating lack of understanding pertaining to arrangement, relations, or organization of anatomy.	I am still unsure of how the different chambers and sections of the heart are connected. I'm still struggling to get the sides of the heart and the ventricle and atrium right.
Function/Path understanding	FP	Statement indicating lack of understanding of a mechanical or biochemical processes resulting in a specific outcome.	How it circulates through the different parts of the heart…. What role do the lungs play in the circulatory system?
Other	O	Statements that do not fit in the S, FP, or T category	How people in a vegetative state stay alive. How about energy?

* Multiple can be assigned.

APPENDIX G

CODING RUBRIC USED FOR SCORING THE KNOWLEDGE

INFERENCE POSTTEST ASSESSMENT

(GADGIL ET AL. 2012)

Number	Question	Idea Unit/Coding	Point award
1	Why is the heart divided into chambers?	To separate right and left so that oxygenated and deoxygenated don't mix	1
		Upper and lower to separate holding tanks	0.5
		And actual pumps	0.5
2	Why is it not necessary for capillaries and arteries to have valves?	Capillaries: too small	1
		Arteries: blood already under high pressure	0.5
		Less chance of backflow	0.5
3	How can we tell whether a blood vessel is a vein or an artery, on the basis of its purpose?	Veins carry blood towards heart	0.5
		Arteries carry blood away from the heart	0.5
4	What is the function of the circulatory system?	To supply oxygen OR nutrients to body	1
5	Why is your right ventricle less muscular than your left ventricle?	Right pumps to lungs	0.5
		Left to all the body	0.5
6	Why does the blood need to go to the heart first before it goes to the lungs, after it has traveled throughout the body?	So it is under enough pressure to be pumped to body parts	1

7	Why don't we have valves in pulmonary veins?	The pulmonary vein is really an artery that has flow from the lungs to the heart.	1
8	Why do vessels get increasingly smaller as they get further towards the body cells and increasingly larger as they get nearer the heart?	Smaller to allow diffusion	1
		Larger to enter heart at a common point in the atrium	1
9	What would be the consequence of having a hole in the septum?	Oxygenated and deoxygenated would mix between the atria and/or the ventricle	1
10	If the heart isn't functioning properly and somehow pumps slower than normal, is there a decrease in the total volume of blood in the circulatory system? That is, is there less blood to pump? Explain.	No + closed loop	1
		No + total volume is same	1
11	The artery that carries blood from the right side of the heart to the lungs (the pulmonary artery) carries about the same amount of blood as the artery that carries blood from the left side of the heart to the rest of the body (aorta). Why do they carry the same amount of blood?	Describes blood contained within a closed loop i.e. Heart>lungs>heart rather than blood goes out to the body with no return.	1
12	Exercise strengthens muscles. Why is this good for circulation?	Good muscle tone	0.33
		Valves close fully	0.33
		Less chance of backflow	0.34
13	Alcohol initially expands the peripheral blood vessels. As a result, the heart beats faster right after alcohol consumption. How would the expansion of blood vessels lead to a faster heart beat?	More blood is forced out per heartbeat	0.33
		Total volume of blood is same	0.34
		Rate increases	0.33
		Total	17

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